SIMULATION OF DRIVER, VEHICLE AND ENVIRONMENTAL ASPECTS OF CRASH INITIATION, A NEW METHOD TO IMPROVE INTEGRATED SAFETY EFFECTIVENESS

R. L. Wood[*], A. D. Dumbuya[*], J. Zhao[*], J. Hill[§], P. D. Thomas[§],
[*]Traffic Modelling and Simulation Group
[§]Vehicle Safety Research Centre
Loughborough University
UK
Paper Number 356

ABSTRACT

New technologies are becoming available to reduce the frequency of crashes. They may be vehicle based or road based and will involve a variety of levels of information provision to drivers and increasing levels of control over the vehicle. Vehicle systems under development include Intelligent Speed Control, Lane keeping, Adaptive Cruise Control, night vision, driver drowsiness detection while road based systems include information services and signalling. Systems development is made on the basis of technological factors, experimental studies and human factors approaches. While improved safety is a prime objective of a number of these systems, there are currently few methods available to systematically assess the in-depth application of the technologies in specific accident situations.

The paper reports on a new methodology for vehicle and traffic simulation that reproduces the drivers' and vehicles' actions in the period leading to a crash. Autonomous driver agents are used to simulate the observations, behaviour and decision making of the driver while vehicle dynamics modules and road modules place the driver within the traffic and road context. To enable virtual drivers to emulate some of the unpredictable behaviour of their human counterparts, each driver agent has the capability to perceive their environment, make decisions based on what they 'see' and take appropriate actions. So far, several aspects of the model have been validated against experimentally derived data.

The model has been used to simulate the pre-crash events leading to cases examined within the UK On-the-Spot Accident study. Case studies are presented and other applications of the simulation methodology relating to driving simulators, virtual road design and other transport applications will also be discussed. The oral presentation will include video run throughs of real-world scenarios and their simulations.

INTRODUCTION

Each year there are over 40,000 traffic fatalities on the roads of the 15 member states of the EU, when under-reporting is taken into account the numbers of injured exceed 3,500,000. The costs to society are immense, quite apart from the pain and suffering the economic penalty to the EU is 166,000,000,000 Euros, exceeding the annual budget of the European Commission (ETSC, 2001). The importance of reducing the impact of road crashes is increasingly widely recognised and the European Commission has adopted a target of a 50% reduction in fatalities by 2010. This ambitious target is being addressed at national and European levels by a variety of methods including improvements in vehicle safety, road infrastructure design, and road user behaviour. In particular active safety technologies are being developed that may have the potential to provide further crash reductions although there is much development needed (ETSC, 2001), (Sferco et al., 2001), (Noy, 2001), (Najim et al., 2001), (Carsten and Tate, 2001). These systems will be simple in operation in the early stages, providing driver support under relatively straightforward driving conditions. Despite this they may be complex technically due to the demanding nature of the traffic, vehicle and road user system within which they must operate.

New technical objectives are identified through the use of both national level and in-depth accident data that can give relatively unambiguous descriptions of the circumstances of accidents and the nature and causation of injuries. Typically an understanding of the events before and during a crash is gained by the use of detailed reconstruction techniques that use physical evidence from the scene and vehicles to simulate the vehicle movements and final rest positions of the crash participants. Nevertheless, although these methods are capable of providing an accurate picture of the events of the crash they do not explain the reasons for those movements, neither do they offer much potential for evaluating accident risk should any factors contributing to the crash be changed.

A new On-The-Spot (OTS) accident research project is now underway in the UK with funding from the Department for Transport and the Highways Agency (Hill et al, 2001). The project has the following objectives:

- To establish an in-depth research database of a representative sample of road accidents in the United Kingdom.
- To better understand the causes of crashes and injuries.
- To support the development of countermeasures.

This project enables expert investigators to attend the scene of an accident within 15 minutes of the incident occurring, which allows the collection of accident data that would otherwise be quickly lost, figure 1.

Figure1. Rapid response is essential.

There are teams at the VSRC in the Midlands of England and TRL in the South. In-depth crash investigations are essential for understanding what happens in the real world. Also, much information necessary to understand complex road safety questions is only found at the scene of the crash, and is lost once the accident scene is cleared. OTS investigations obtain this "perishable" accident data by prompt attendance at the scene to gather information including trace marks on the highway, pedestrian contact marks on vehicles, the final resting position of the vehicles involved, witness interviews, weather, visibility and traffic conditions, figure 2.

Projects such as OTS are significant in developing refined procedures for gathering and reviewing information about real-world incidents, leading to new opportunities to identify the relative influence of various factors in many accidents. These opportunities are further enhanced through the use of computer-based simulation. This can be applied to both normal driving and pre-crash events, taking account of human behaviour, the road and traffic environment, and the dynamic characteristics of vehicles. Such simulation tools have wide-ranging applications, including reconstruction of individual incidents, analysis of parametric changes in the crash environment, assessment of new vehicle and/or infrastructure based safety systems and driver education/training.

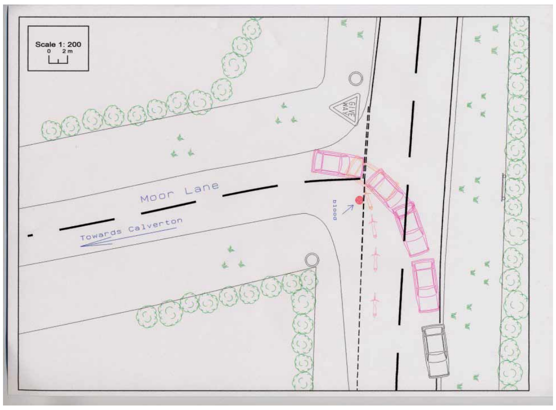


Figure 2. An OTS incident plan.

The following sections provide a brief overview of key simulation methods, leading into discussion of a simulation tool being developed at Loughborough University. Progress in this development is highlighted through two case studies before exploring avenues for further work.

DRIVING AND TRAFFIC SIMULATION METHODS

A broad range of driver and traffic related simulation tools now exist, primarily intended to develop deeper understanding of normal driver behaviour, vehicle interactions and consequent traffic flow (SMARTEST, 1997). The majority of these tools conveniently achieve this by combining the concepts of driver and vehicle into a single entity that can perceive, decide and act within a geometric road network model. A smaller number of simulation tools make a clear distinction between the driver and the vehicle, creating opportunities to additionally explore various aspects of their interaction. Vehicle models in such software typically represent kinematic behaviour, calculating position, velocity and acceleration. In those simulators that use a distinct driver model, such models typically employ Artificial Intelligence techniques, such as fuzzy logic (Wu et al., 1998). or rule - based methods (Wood and Arnold, 1997) to capture key elements of decision making. A fundamental feature of the fuzzy logic approach is its ability to succinctly represent observations of real-world driver behaviour in a compact analytical process. In contrast, rule-based methods are prescriptive and require similar experimental observations for their validation rather than their development. Very few existing simulation tools provide facilities for detailed definition of the highway environment, primarily due to their focus on understanding key features of normal driving in representative circumstances.

Within the context of these alternative approaches, figure 3 shows the primary elements of a simulation tool, 'Synthetic Driving Simulator (SD-SIM)', being developed at Loughborough University (Dumbuya and Wood, 2003). The most novel feature of this tool is that it is based on clear distinctions between drivers, vehicles and the road network, allowing the software to act as a 'framework' that can accommodate varying levels of detail to match the needs of different applications.

The Intelligent Virtual Driver model shown within figure 3 is concerned with perception of the driver's environment, decision making and action execution. Perception currently involves vision of the local traffic environment, allowing estimation of other vehicles' speeds and relative positions. Perception can, however, be extended to include visual and auditory perception of the vehicle interior, for example in the use of telematic systems, along with mechanical perception of forces imposed on the driver by vehicle movement. Decision making within the driver model uses a small number of rules, each having a weight or importance factor. These weights, along with parameters in some of the rules, can be adjusted to characterise a wide spectrum of driver behaviour. The outcome of decision-making is the intention to change vehicle speed and/or direction. This is enabled by the Execute Action Model, which provides an interface from the driver to the vehicle.

Work funded by the UK Highways Agency is currently underway to integrate a model of vehicle dynamics within the framework, providing an alternative to the existing vehicle kinematics model. This will not only allow significantly enhanced vehicle behaviour, but will also allow this behaviour to be sensed by the driver, as previously mentioned. A further implication of introducing realistic vehicle dynamics is that it creates the need for accurate highway definition. This is, firstly, to ensure that simulation results are not contaminated by poor modelling, for example unrealistically sharp changes in gradient leading to fictitious suspension behaviour and, secondly, to capture key factors, such as friction due to surface condition.

To make this broad ranging functionality easily usable, it is essential to have a convenient means of defining the characteristics of drivers, vehicles and the highway. This is achieved through the Scenario Modeller, in figure 3. It is also essential that simulation results can be interrogated in various ways to obtain maximum insight, through the Animation Visualiser.

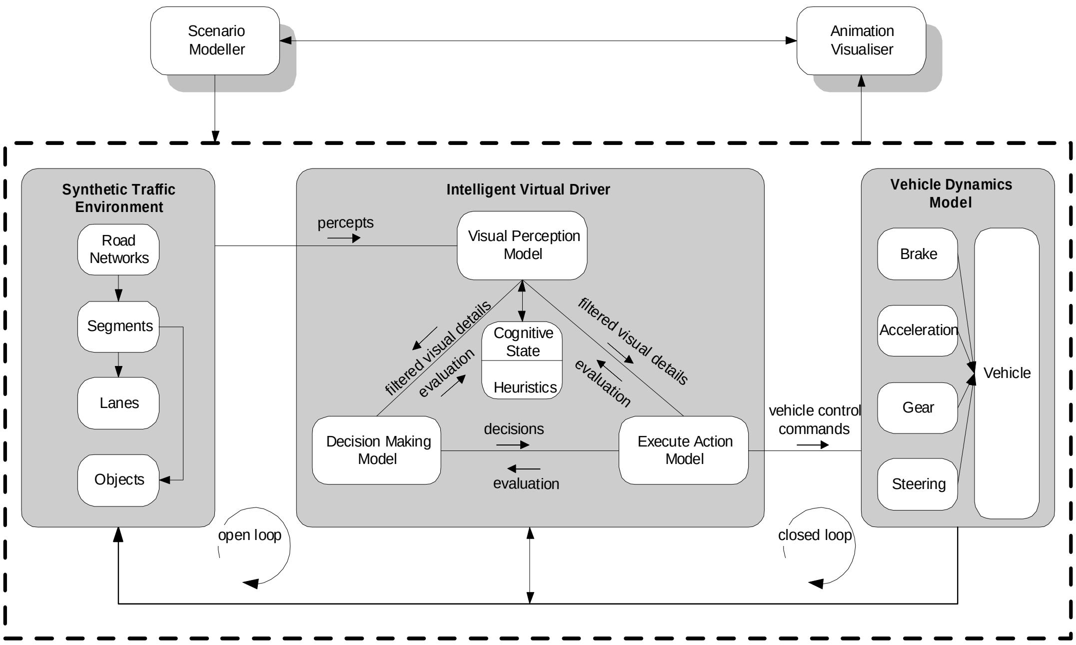
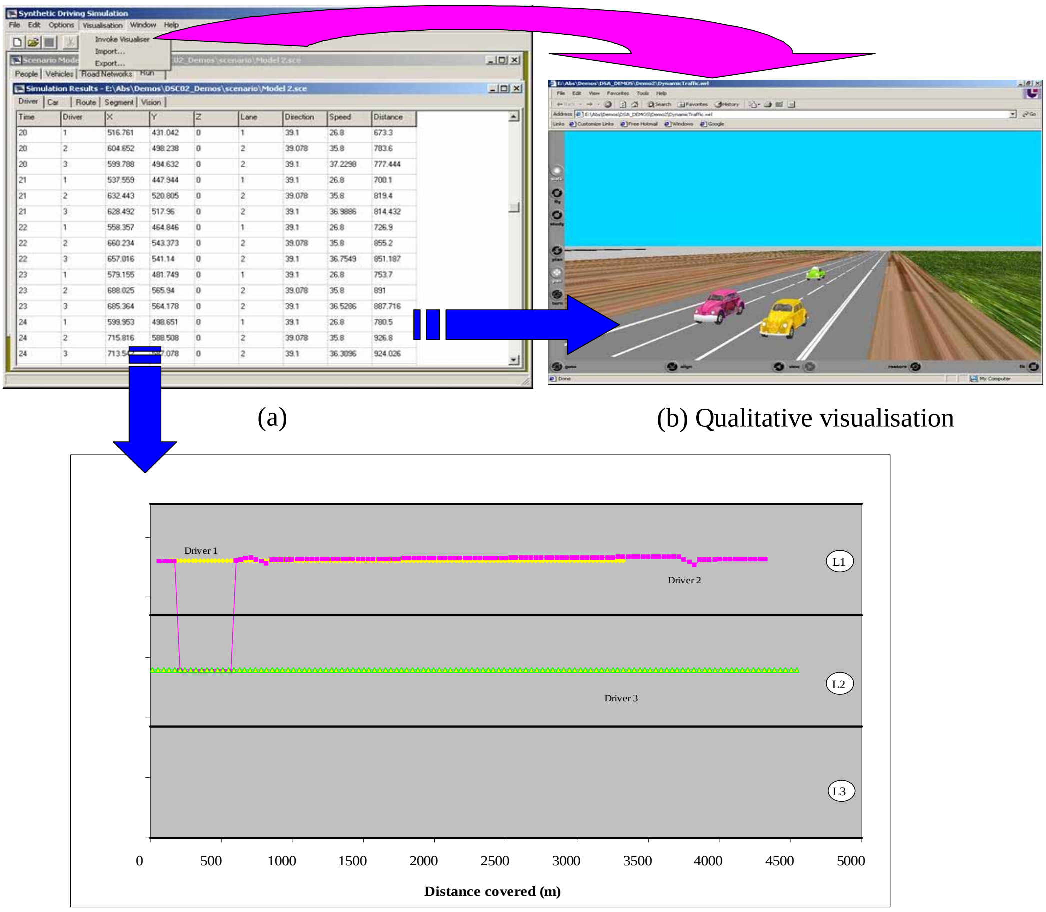


Figure 3. Functional structure of SD-SIM.

CASE STUDIES

Two case studies are briefly presented, one concerning normal driving and the other investigating an accident. The first, shown in figures 4 and 5, involves interaction between three vehicles on a flat 3-lane road and demonstrates how raw simulation results (a) can be viewed as qualitative movies (b) and quantitative charts (c). Figure 5 also indicates that qualitative visualisation extends to viewing scenarios from multiple viewpoints, including those of individual drivers.



(a)

(b) Qualitative visualisation

(c) Quantitative visualisation

Figure 4. Both qualitative and quantitative visualisation are important.

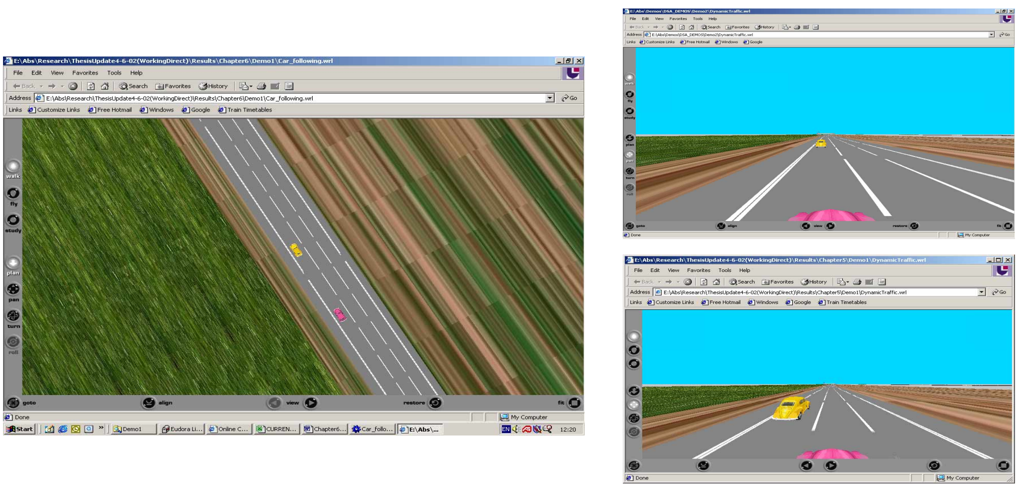


Figure 5. Multiple qualitative viewpoints can be explored.

The second case study concerns a collision between a Ford Sierra and Land Rover Freelander investigated by the OTS team at the VSRC. The incident took place in the dark on a Winter evening and the road was a single carriageway subject to the 60 mph (96 km/h) National speed limit. The incident plan shown in figure 6 indicates that the Sierra and Freelander approached from left and right, respectively. Intending to overtake other traffic, the Sierra driver moved out into the path of the Freelander and the vehicles collided. Other road users reported that Sierra driver had been driving erratically for some distance prior to the impact, having steered the vehicle from kerb to median line on several occasions and made a series of erratic overtaking manoeuvres. Witness and damage evidence suggest that the Sierra's approach speed was probably between 60 and 75 mph (96 – 120 km/h). Little is known about the driving style of the Freelander upon approach. The driver claimed not to have seen the Sierra move out into his path, and subsequently took late avoiding action that included heavy braking. Tyre marks were caused by wheel lock up on braking, and these allowed the vehicle to be accurately placed on the road at that point. The Freelander's approach speed, suggested from witness and damage evidence, was around 50 to 65 mph (80 – 104 km/h). In developing the simulation, parameters controlling the driver vision model were adjusted to reflect local lighting conditions. Investigation data was used to interpret the drivers' behaviour prior to impact in terms of the rules, weights and parameters in the previously discussed driver model. This was done iteratively, comparing simulation results with investigation data. Figure 7 shows (a) a frame from the OTS location video, along with (b), (c), (d) frames recorded from various viewpoints in the incident simulation. Figure 8 provides quantitative examination of the simulated incident.

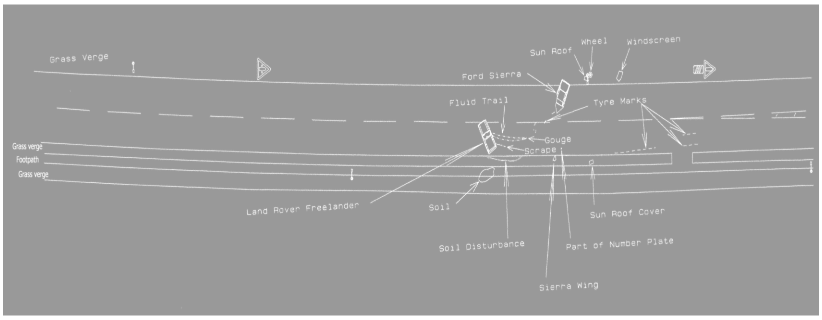
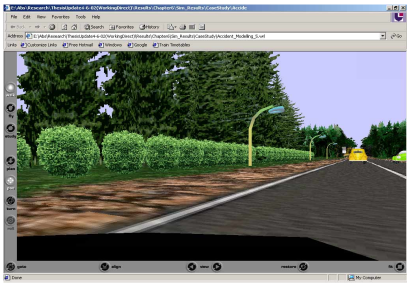
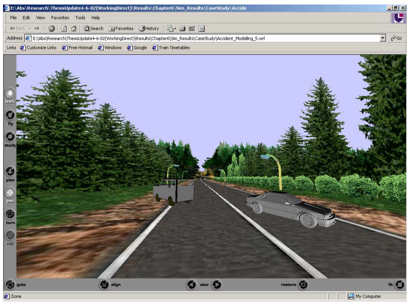


Figure 6. An Incident Plan Describing the OTS Case Study.

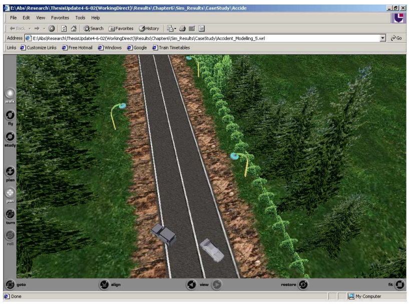
(a) Video footage of the location.



(b) A driver's view prior to crash.



(c) Eye level view of the crash scene.



(d) Ariel view of the crash scene.

Figure 7. Qualitative views of the incident.

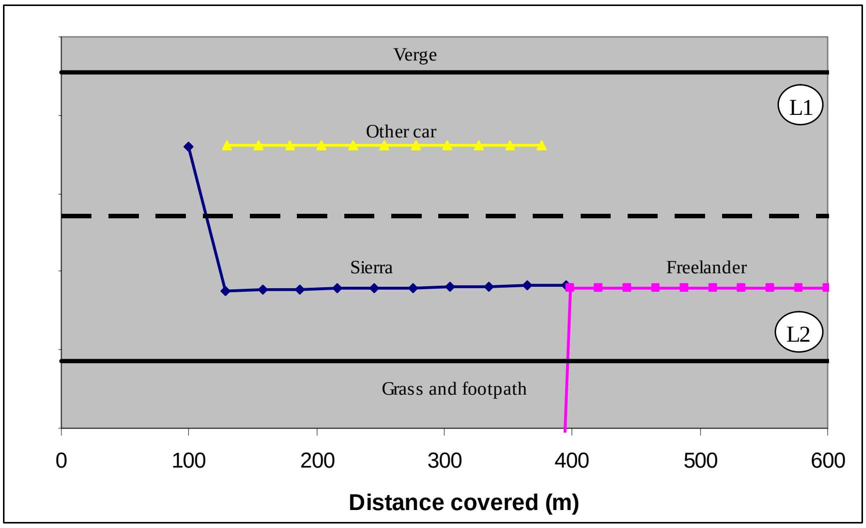


Figure 8. A quantitative view of the simulated incident.

DISCUSSION

SD-SIM is at a relatively early stage of development, but is already proving valuable in several types of analysis. An important aspect of this has been the initial concept of creating an open 'framework' software design. This not only allows progressive improvement of constituent models, but also maintains a balanced view of the need to model drivers, vehicles and road networks as separate interacting elements. More generally, simulation technology, exemplified here by SD-SIM, has a variety of applications that increase the understanding of accident causation and permit a quantitative prediction of relative accident risk. Application areas extend from the reconstruction of specific crash events, to the parametric evaluation of vehicle and highway based accident avoidance measures:

Crash Reconstructions

Classical accident reconstruction techniques use residual traces and damage to evaluate the pre-crash dynamics of the vehicles involved. The SD-SIM tool additionally enables the particular characteristics of the drivers to be modelled within a realistic traffic context. For example the simulation has the potential to reflect levels of intoxication, impaired vision or reaction times of the driver. Visualisation software is widely available that demonstrates the vehicle kinematics from a variety of fields of view but these do not generally take account of visual defects of drivers or the conspicuity of other road uses.

Parametric Studies

An accident simulation that is based on realistic driver, vehicle and traffic characteristics holds the possibility of being used for parametric studies to evaluate the probability of alternative outcomes in different circumstances. For example if an aspect of the dynamic characteristics of the vehicle are judged to have increased the risk of a crash then the simulation can be modified to assess the likelihood of a crash. The characteristics of the specific drivers involved can be replaced using multiple driver agents representing the complete range of driver attributes in the proportions observed on the road. Absolute estimates of risk of a crash can then be obtained by driving these simulated vehicles repeatedly through the crash environment. Alternatively, proposed changes to existing road features (possibly following an accident at a specific location) may be evaluated before implementation. This simulation-based approach has the potential to become a central road safety engineering tool.

Active Safety Systems

New technology systems are being developed that may be vehicle or highway based that utilise information from road or vehicle sensors to reduce the risk of a crash. Already systems such as Electronic Stability Control and night vision enhancement are available on cars. Other systems include brake assist, lane departure, automatic cruise control and systems to detect an imminent collision. The simulation of realistic traffic can be used to evaluate the human factors aspects that may limit the effectiveness of the systems. For example the vision module within the simulation can be set to the characteristics of a vehicle with and without night vision and the benefit assessed for a range of drivers to enable risk evaluations, the availability of a range of driver profiles will support the assessment of the system with regard to typical drivers, including varying propensity for higher risk taking. Such evaluations would not be practical under real-driving conditions.

Driving Simulators

Driving simulators are widely available and they have increasing complexity to reproduce the dynamic motions associated with driving scenarios, sophisticated visualisation technologies are used to provide a convincing sense of reality to simulator users. Typically a road environment is programmed although video recordings of real-roadways may be used. The behaviour of other road users though is not simulated within conventional systems, in particular the unpredictability of a normal traffic mix is difficult to reproduce in a simulator. The driver agents within SD-SIM can be used to direct the movements of other vehicles so that a range of traffic conditions are simulated. Driving simulators are increasingly being used to evaluate the abilities of people who may be elderly or have had impairing illnesses. Using the models within SD-SIM these drivers can be placed in increasingly demanding driving situations and their performance compared with the normal driving population.

Education And Training

Simulation provides a novel opportunity to influence accident statistics through enhanced driver education, particularly applied to learners and those convicted of driving offences. A key element of this is the flexibility of qualitative visualisation, enabling a scenario to be seen from various viewpoints. Such scenarios could be simulations of real world situations originally captured on video, or could be entirely fictitious, allowing incorporation of significant risk.

CONCLUSIONS

Computer-based simulation offers a new opportunity to reduce the frequency and severity of road traffic accidents, with associated reductions in human trauma and economic consequences. In addition to its use in accident analysis, this paper has highlighted a range of safety related applications in which simulation can make an important contribution. Underpinning various simulation tools, key modelling techniques have been identified that support representation of drivers, vehicles and road networks, allowing the detail within each to be matched to the needs of different applications.

ACKNOWLEDGEMENTS

The authors are grateful for ongoing funding and support provided by the UK Highways Agency in the development of this project. The OTS project is funded by the Department for Transport (DfT) and the Highways Agency (HA). In addition, the authors would like to thank the Chief Constable of Nottinghamshire Police and his officers for their ongoing support with the OTS project at the VSRC, and more specifically officers at the Crash Investigation Unit for providing the scene plan presented in this paper. The views expressed in this paper belong to the authors and are not necessarily those of the DfT, HA or Nottinghamshire Police."

REFERENCES

Carsten, O.; Tate, F. Intelligent Speed Adaption: The Best Collision Avoidance System? Paper Number 324 at the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV). U.S. Department of Transportation. National Highway Traffic Safety Administration. DOT HS 809 220. Amsterdam June 4-7, 2001.

Dumbuya, A. D., and Wood, R.L. 2003, Visual perception modelling for intelligent virtual driver agents in synthetic driving simulation. Journal of Experimental and Theoretical Artificial Intelligence (JETAI), **15** (1): 73–102.

European Transport Safety Council (ETSC). Priorities for EU Motor Vehicle Safety Design. Rue du Cornet 34, B-1040, Brussels. www.etsc.be. Report published in 2001.

Hill, J.R.; Thomas, P.; Smith, M.; Byard. N.; Rillie; I. The Methodology of On The Spot Accident Investigations in The UK. Paper Number 350 at the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV). U.S. Department of Transportation. National Highway Traffic Safety Administration. DOT HS 809 220. Amsterdam June 4-7, 2001.

Najim, W.G.; Koopmann, J.A.; Smith, D.L. (U.S. Department of Transportation). Analysis of Crossing Path Crash Countermeasure Systems. Paper Number 378 at the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV). U.S. Department of Transportation. National Highway Traffic Safety Administration. DOT HS 809 220. Amsterdam June 4-7, 2001.

Noy, Y. I. (Transport Canada). International Harmonizatized Activities Report of Working Group in Intelligent Transport Systems (ITS). Paper Number 445 at the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV). U.S. Department of Transportation. National Highway Traffic Safety Administration. DOT HS 809 220. Amsterdam June 4-7, 2001.

Sferco, R.; Page, Y.; Le Coz, J.; Fay, P. Potential Effectivness of Electronic Stability Programs (ESP) – What European Field Studies Tell Us. Paper Number 327 at the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV). U.S. Department of Transportation. National Highway Traffic Safety Administration. DOT HS 809 220. Amsterdam June 4-7, 2001.

SMARTEST Project Deliverable D3, August 1997, European Commission, 4th Framework Programme, Transport RTD Programme, Contract No: RO-97-SC.1059

Wood, R. L., and Arnold, J.E. 1997. An automata based simulation of co-operative decision making. Application of AI in Engineering, (Computational Mechanics Publications, 1997), pp. 105-109.

Wu, J., McDonlad, M., and Brackstone, M., 1998, A fuzzy logic microscopic simulation model for interurban ATT assessment. In Proceedings of 10th European simulation symposium (ESS'98), Nottingham, pp. 347–354.